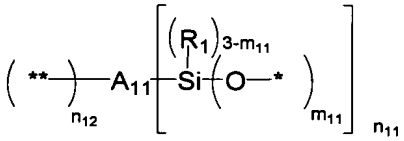
CLAIMS

1. A proton-exchange membrane having a structure of mesogen-containing organic molecular chains and a proton-donating group-containing group covalent-bonding to a silicon-oxygen three-dimensional crosslinked matrix, in which at least a part of the organic molecular chains are oriented to form an aggregate thereof.

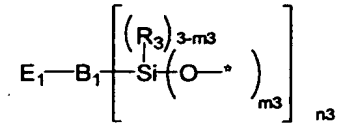
2. The proton-exchange membrane of claim 1, which contains a partial structure of the following formula (I):



... (I)

wherein A_{11} represents a mesogen-containing organic atomic group; R_1 represents an alkyl group, an aryl group or a heterocyclic group; m_{11} indicates an integer of from 1 to 3; n_{11} indicates an integer of from 1 to 8; n_{12} indicates an integer of from 0 to 4; * indicates the position at which the structure bonds to a silicon atom; and ** indicates the position at which the structure bonds to an organic polymer chain.

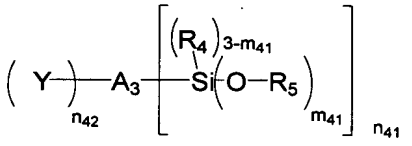
3. The proton-exchange membrane of claim 1, wherein the proton-donating group covalent-bonds to the silicon-oxygen three-dimensional crosslinked matrix via a structure of the following formula (III):



... (III)

wherein B_1 represents a linking group that contains an aliphatic group and/or an aromatic group; R_3 represents an alkyl group or an aryl group; E_1 represents a proton-donating group; m3 indicates an integer of from 1 to 3; n3 indicates an integer of from 1 to 4; and * indicates the position at which the structure bonds to a silicon atom.

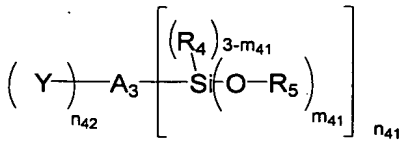
4. The proton-exchange membrane of claim 1, which is obtained through sol-gel reaction of a precursor, organosilicon compound of the following formula (IV):



... (IV)

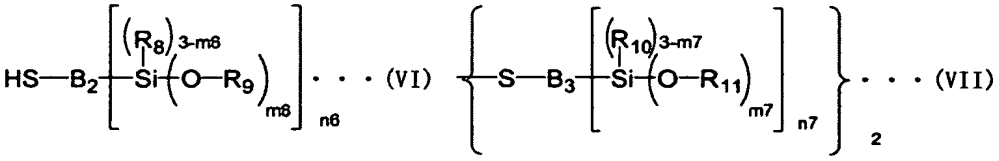
wherein A_3 represents a mesogen-containing organic atomic group; R_4 represents an alkyl group, an aryl group or a heterocyclic group; R_5 represents a hydrogen atom, an alkyl group, an aryl group or a silyl group; Y represents a polymerizing group capable of forming a carbon-carbon bond or a carbon-oxygen bond through polymerization; m_{41} indicates an integer of from 1 to 3; n_{41} indicates an integer of from 1 to 8; n_{42} indicates an integer of from 0 to 4; when m_{41} is 2 or more, R_5's may be the same or different.

5. The proton-exchange membrane of claim 1, in which is used a sulfonic acid sol obtained through oxidization of a solution that contains an organosilicon compound of the following formula (IV), and an organosilicon compound of the following formula (VI) and/or (VII):



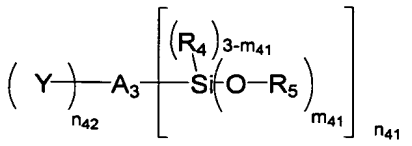
... (IV)

wherein A_3 represents a mesogen-containing organic atomic group; R_4 represents an alkyl group, an aryl group or a heterocyclic group; R_5 represents a hydrogen atom, an alkyl group, an aryl group or a silyl group; Y represents a polymerizing group capable of forming a carbon-carbon bond or a carbon-oxygen bond through polymerization; m_{41} indicates an integer of from 1 to 3; n_{41} indicates an integer of from 1 to 8; n_{42} indicates an integer of from 0 to 4; when m_{41} is 2 or more, R_5's may be the same or different,



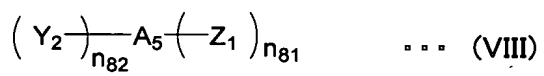
wherein B_2 and B_3 each represent a linking group that contains an aliphatic group and/or an aromatic group; R_8 and R_{10} each represent an alkyl group or an aryl group; m6 and m7 each indicate an integer of from 1 to 3; n6 and n7 each indicate an integer of from 1 to 4; R_9 and R_{11} each represent a hydrogen atom, an alkyl group, an aryl group or a silyl group; when m6 or m7 is 2 or more, R_9's or R_{11}'s may be the same or different.

6. The proton-exchange membrane of claim 1, which is obtained through sol-gel reaction of a compound of the following formula (IV) with from 1 mol% to 50 mol% of a compound of the following formula (VIII):



... (IV)

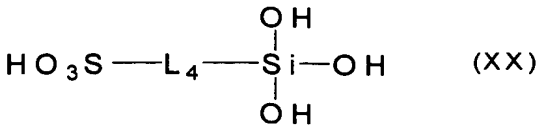
wherein A_3 represents a mesogen-containing organic atomic group; R_4 represents an alkyl group, an aryl group or a heterocyclic group; R_5 represents a hydrogen atom, an alkyl group, an aryl group or a silyl group; Y represents a polymerizing group capable of forming a carbon-carbon bond or a carbon-oxygen bond through polymerization; m_{41} indicates an integer of from 1 to 3; n_{41} indicates an integer of from 1 to 8; n_{42} indicates an integer of from 0 to 4; when m_{41} is 2 or more, R_5's may be the same or different,



... (VIII)

wherein A_5 represents a mesogen-containing organic atomic group; Z_1 represents a substituent not changing in sol-gel reaction, or a hydrogen atom; n_{81} indicates an integer of from 1 to 8; n_{82} indicates an integer of from 0 to 4; Y_2 represents a polymerizing group capable of forming a carbon-carbon bond or a carbon-oxygen bond through polymerization; when n_{81} is 2 or more, Z_1's may be the same or different.

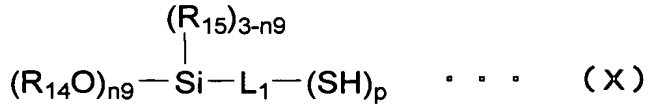
7. The proton-exchange membrane of claim 1, in which is used a sol obtained through hydrolysis and polycondensation of a precursor of the following formula (XX) in the presence of water and an oxidizing agent:



(XX)

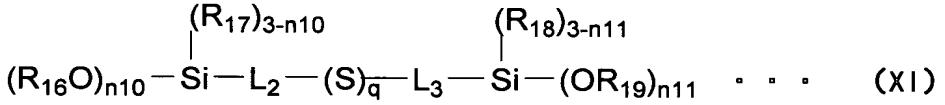
wherein L_4 represents a divalent linking group.

8. The proton-exchange membrane of claim 1, in which is used a sol obtained through hydrolysis and polycondensation of a precursor of the following formula (X) and/or (XI) in the presence of water and an oxidizing agent:



$$(R_{14}O)_{n9}-Si(-(R_{15})_{3-n9})-L_1-(SH)_p \quad \cdots \quad (X)$$

wherein L_1 represents a (p+1)-valent linking group; R_{14} and R_{15} each represent an alkyl group or an aryl group; n9 indicates 2 or 3; at least one R_{14} is an alkyl or aryl group having at least 3 carbon atoms; R_{14}'s may be the same or different; and p indicates an integer of from 1 to 3,



$$(R_{16}O)_{n10}-Si(-(R_{17})_{3-n10})-L_2-(S)_q-L_3-Si(-(R_{18})_{3-n11})-(OR_{19})_{n11} \quad \cdots \quad (XI)$$

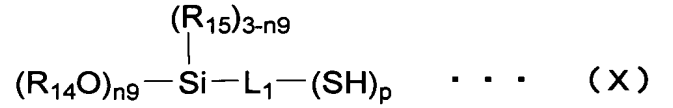
wherein L_2 and L_3 each represent a divalent linking group, R_{16} to R_{19} each represent an alkyl group or an aryl group; n10 and n11 each indicate 2 or 3; at least one R_{16} and at least one R_{19} each are an alkyl or aryl group having at least 3 carbon atoms; R_{16}'s and R_{19}'s each may be the same or different; and q indicates an integer of from 2 to 4.

9. A membrane electrode assembly comprising the proton-exchange membrane of claim 1.

10. A fuel cell comprising the proton-exchange membrane of claim 1.

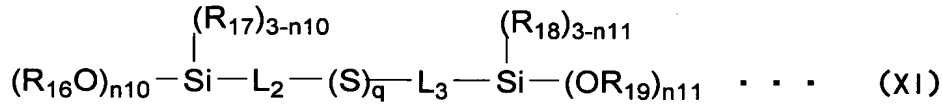
11. A silica sol composition obtained through hydrolysis and polycondensation of at least one precursor of the following formulae (X) and (XI) in the presence of water and an oxidizing

agent:



$$(R_{14}O)_{n9}-Si(-(R_{15})_{3-n9})-L_1-(SH)_p \quad \cdots \quad (X)$$

wherein L_1 represents a (p+1)-valent linking group; R_{14} and R_{15} each represent an alkyl group or an aryl group; n9 indicates 2 or 3; at least one R_{14} is an alkyl or aryl group having at least 3 carbon atoms; R_{14}'s may be the same or different; and p indicates an integer of from 1 to 3,



$$(R_{16}O)_{n10}-Si(-(R_{17})_{3-n10})-L_2-(S)_q-L_3-Si(-(R_{18})_{3-n11})-(OR_{19})_{n11} \quad \cdots \quad (XI)$$

wherein L_2 and L_3 each represent a divalent linking group, R_{16} to R_{19} each represent an alkyl group or an aryl group; n10 and n11 each indicate 2 or 3; at least one R_{16} and at least one R_{19} each are an alkyl or aryl group having at least 3 carbon atoms; and q indicates an integer of from 2 to 4.